VOLTAGE RECOVERY TIME OF SMALL SPARK GAPS*

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Summary

A two-pulse method is used to determine how fast and to what degree a small spark gap can recover its voltage holdoff capability after being discharged. The first pulse is used to overvolt and break down the gap, and the second pulse is used, after a time delay, to determine the voltage holdoff of the ionized gap. By varying the time delay to the second pulse, a recovery voltage versus time plot can be obtained. Time delays from 10 μs to 100 ms have been recorded. The spark gap discharges millijoules of energy with a gap spacing of less than 1 mm. Breakdown voltages of up to 10 kV have been achieved in a variety of gases. The experimental setup, pulse circuits, and data collection methods are described. Recovery voltage versus time plots for various parameters (gas species, gap spacing, pressure) are discussed along with their statistical variation.

Introduction

Many applications of pulse power require high repetition rate spark gap switching. In order to better understand the dominant factors involved with gaseous spark gap recovery, investigations are being made to determine the recovery holdoff voltage as a function of time for small spark gaps. To obtain this information, two high voltage pulses are applied to the spark gap with a variable time delay between them. The first pulse is used to overvolt and break down the gap, and the second pulse is used to determine the voltage holdoff (recovery) of the gap after the time delay. A plot of recovery voltage versus time can be obtained by varying the time delay between the first and second pulses. This delay can be varied from less than 10 μs to greater than 100 ms. The time between pulse pairs is about one second. The spark gap used for this data is an untriggered, pressurized gas spark gap which has approximately Rogowski shaped electrodes about one centimeter in diameter. The gap spacing is in the range from 5 to 20 mils and the energy discharged is millijoules with breakdown voltages of several kV. This paper describes the initial effort to determine some of the important parameters and problem areas involved with this type of experiment as well as the performance characteristics of the experimental setup and procedure.

Two-Pulse Circuit

The circuit employed to generate the high voltage pulse pairs is shown in Figure 1. Capacitors C1 and C2 are charged through R1 and R2 by the power supply. A pulse from output one of the trigger-delay generator turns on ASCR-1 which allows C1 to discharge through the primary of the pulse transformer, T. The secondary winding is connected to the spark gap under test and produces a high voltage pulse across it. After a variable time delay, output two of the trigger/delay generator turns on ASCR-2 and a second voltage pulse is applied to the gap as C2 discharges through the

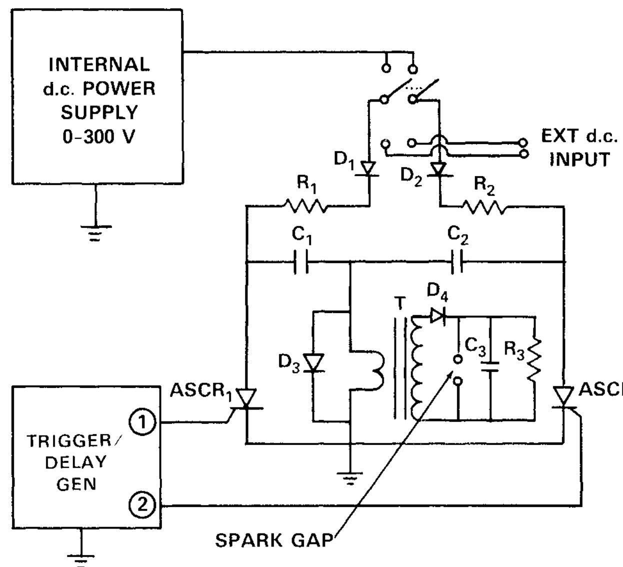

Figure 1. Schematic of two pulse circuit.

primary of T. A small high voltage capacitor, C3, is connected directly across the spark gap to provide energy storage for the discharge. Diodes D1 and D2 permit C1 and C2 to be charged to different voltages from an external source if desired. R3, D3 and D4 damp oscillations in the transformer and spark gap. The values of C1, C2, C3 and the transformer characteristics may be varied to change the voltage, energy and rise time produced across the gap. A typical rate of rise of the voltage across the gap is 5 kV/μs and a typical rise time is less than one μs as shown in Figure 2.

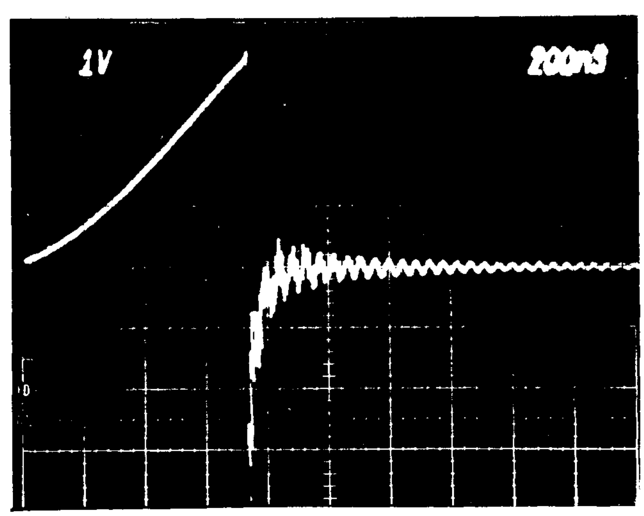

Figure 2. Voltage Waveform across the gap.

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Spark Gap Design

A cross section of the spark gap is shown in Figure 3. It is arranged in a coaxial structure where the center conductor is broken to form the gap. The impedance of the structure is 12 Ω and the end is terminated in 12 Ω using carbon resistors. The capacitance of the coaxial structure is 110 pf which is C3 in Figure 2. The inner and outer conductors are made of copper and the dielectric is made from Castall 300, a ceramic filled epoxy resin. The electrode tips are removable and are presently made of brass. Surrounding the electrodes is a collar made of Macor, a machineable ceramic. One electrode is adjustable by a micrometer to accurately vary the gap spacing.

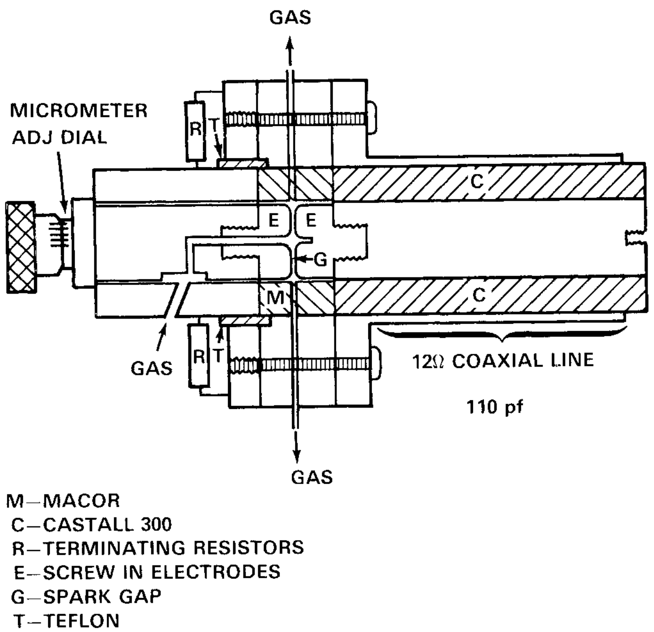

Figure 3. Cross section of spark gap.

The electrode surfaces have been conditioned by more than one million discharges. Gas enters the gap spacing through a hole in the center of one electrode and exists through holes in the sides of the gap area. The gas flows through the gap at about 0.3 cc/sec which allows the gas to remain essentially motionless between the first and second pulses, but to exchange completely before the next pulse pair. Voltage is applied across the coaxial conductors and is measured at the same location with a Tektronix high voltage probe.

Data Recording Method

Data are taken photographically in two forms, both of which are multiple image exposures made with an oscilloscope camera. In the first type of photograph, shown in Figure 4, the scope is triggered on the first pulse of each pulse pair. This places each first pulse trace at the same spot on the left side of the photograph. The time delay to the second pulse is slowly increased for each pulse pair so that a multiple image photograph is created which shows the breakdown voltage as a function of time delay between pulses. In the second type of photograph, the time delay between pulses is fixed at one half the screen width. The position of the traces on the scope is slowly moved halfway across the screen while the shutter is open. This produces a multiple image photograph shown in Figure 5, which shows a series of first pulse breakdowns on the left half of the photo and a series of second pulse breakdowns on the right half. This indicates the statistical variation of the breakdown voltage of the first and second pulses and a statistical comparison of the pulse pairs for one particular time delay.

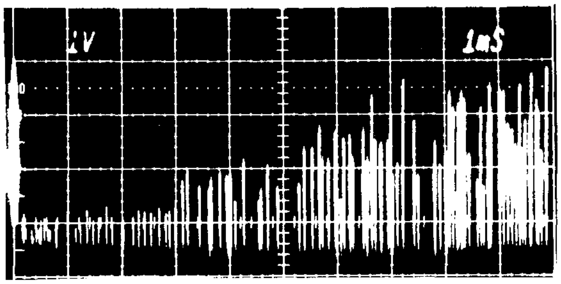

Figure 4. Swept time delay. First pulse position fixed.

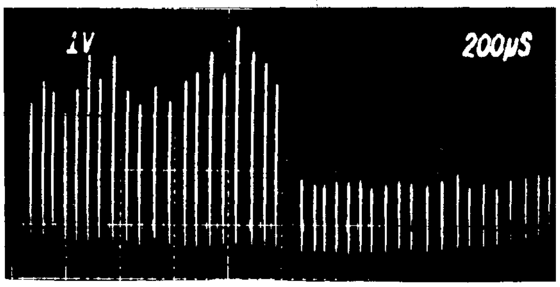

Figure 5. Swept position--time delay fixed.

In generating multiple image photographs, a problem exists because of high intensity blooming of the baseline that tends to obscure the faint voltage pulse images. This problem has been removed by utilizing a high gain inverting amplifier to control the intensity of the trace. The original voltage signal is amplified and inverted and is fed back into the Z axis input of the oscilloscope as shown in Figure 6. This causes the intensity of the trace to be reduced at low amplitudes thereby decreasing or eliminating the baseline.

As is evident from Figures 4 and 5, there is a significant statistical variation between events. The first and second pulse breakdowns, for a given pressure and gap spacing, frequently vary by a factor of 2. Also, for a given time delay, the ratio of the first pulse to the second pulse frequently varies by a factor of 4. The second pulse may even be greater than the first. It appears that this variation is due to the statistical time-to-breakdown which allows the rising voltage pulse to fire the gap at different amplitudes and therefore to be overvolted to different degrees. In taking data it is therefore necessary to do some averaging. Data for the graphs was taken by choosing a time delay between pulses and making multiple image photographs similar to Figure 5. This gives about thirty pulse pairs which are averaged to give the breakdown and recovery voltage for that time delay This forms one point on the graph. End points of the graphs were obtained from time sweep photographs similar to Figure 4.

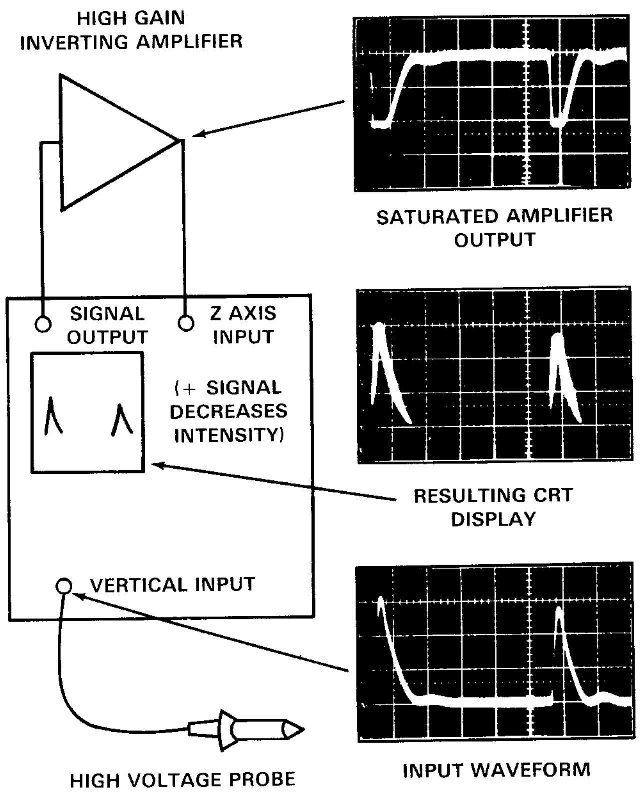

Figure 6. Baseline blanking scheme.

Experimental Results

Three gases have been tested. They are hydrogen, argon, and a mixture of 95% argon and 5% hydrogen by volume. Plots of percent recovery versus time are shown in Figures 7, 8 and 9. Note that for argon, increasing pressure from 0 psig to several hundred psig decreases recovery time by one order of magnitude. For hydrogen, this change gives three orders of magnitude. Hydrogen is an order of magnitude slower than argon at low pressure, but an order of magnitude faster than argon at high pressure. The mixture of hydrogen and argon falls between the curves for the separate gases. Another trend is for the shape of the curves to shift from concave up at low pressures to straight or slightly concave down at high pressures. The hydrogen-argon mix was tested at two spacings, 5 mils and 15 mils. The smaller gap spacing showed a weak tendency to recover faster at all pressures (Figure 10).

The degree of overvoltage was measured by comparing the static breakdown voltages to the average pulse breakdown voltages. Static breakdown Paschen curves are shown in Figure 11. As would be expected with a linear rise time, low pressures are overvolted more than high pressures since the statistical time is a larger percentage of the pulse rise time. Figure 12 shows an example of voltage recovery versus time in terms of the percentage of static breakdown voltage for argon. This curve shows that at low pressures the spark gap is overvolted by several times the static breakdown, but at high pressures almost no overvolting occurs.

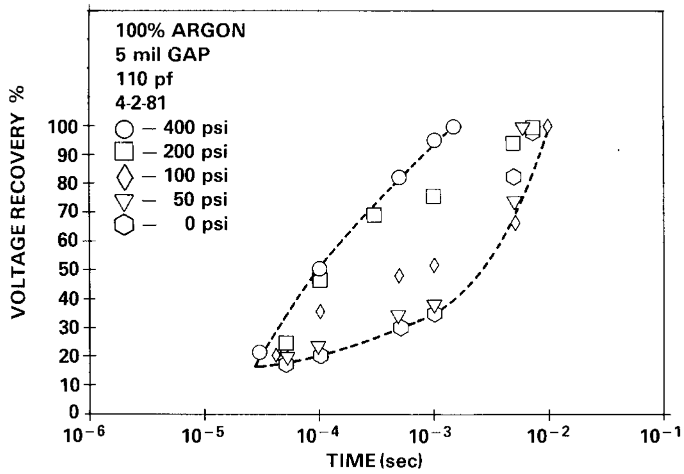

Figure 7. Percent recovery versus time for argon.

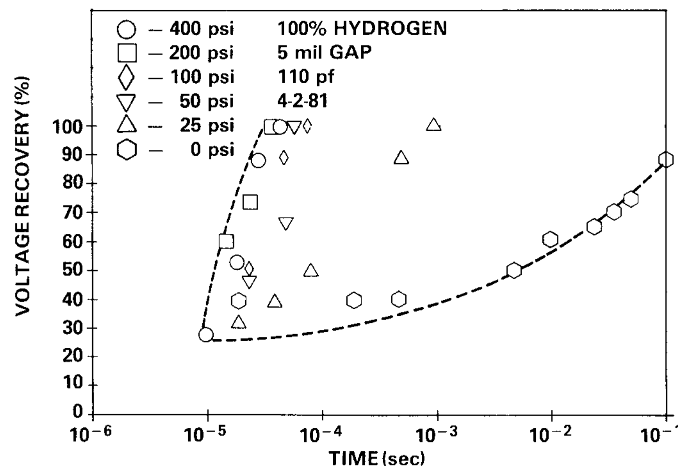

Figure 8. Percent recovery versus time for hydrogen.

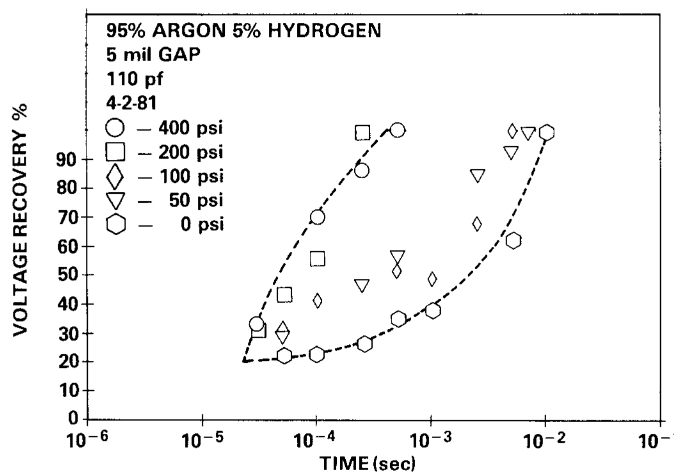

Figure 9. Percent recovery versus time for hydrogen-argon mix.

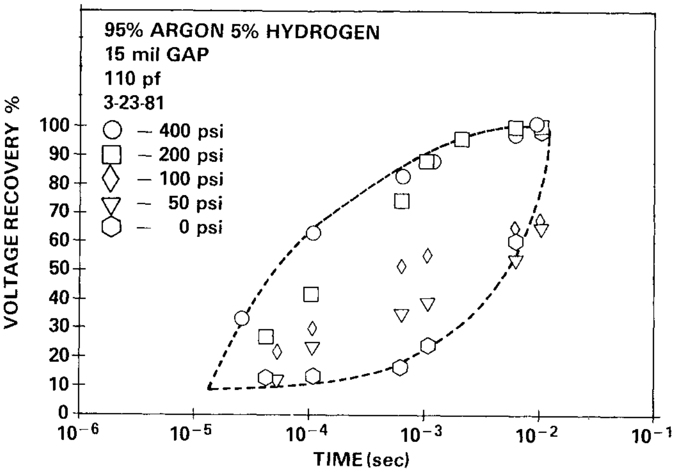

Figure 10. Percent recovery versus time for hydrogen-argon mix (15 mil gap).

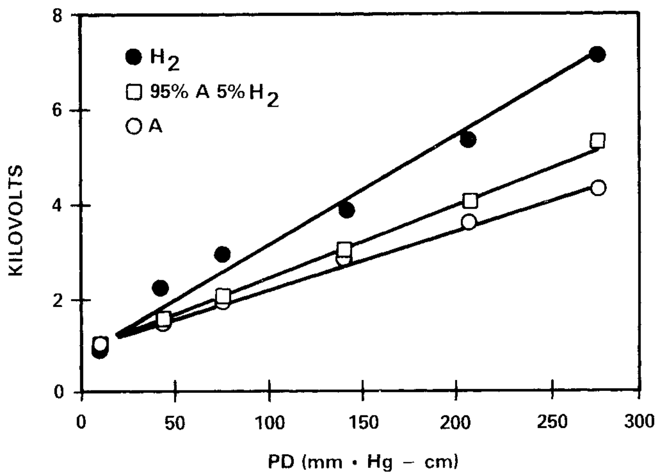

Figure 11. Paschen curves.

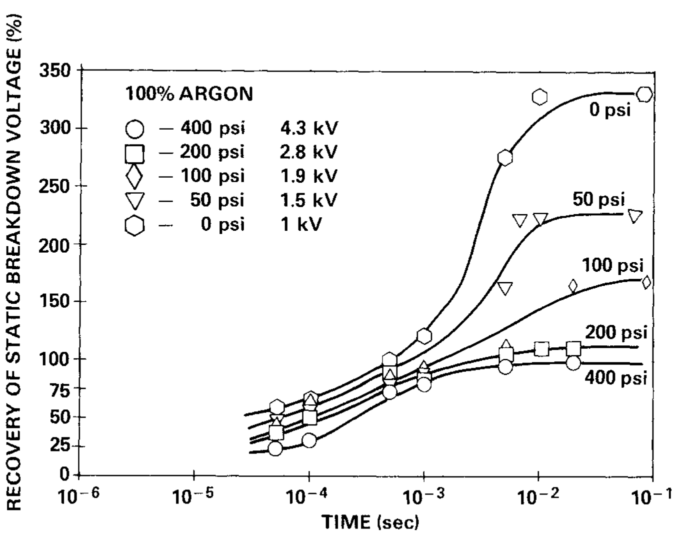

Figure 12. Percent recovery of static breakdown voltage in argon.

Conclusions

Some rough conclusions have been drawn from the experimental results. The gas species and pressure are very important parameters in determining recovery times. The two-pulse method utilizing a trigger/delay circuit to create a variable time delay between pulses works well, as does the photographic data collection using Z axis blanking. The statistical variation in both the breakdown voltage and the degree of overvoltage is large because the pulse rise time is long compared to the statistical time to breakdown. It is therefore desirable for the voltage to rise quickly compared to the time to breakdown and to remain constant until the gap fires. The intent is to upgrade the present experimental setup using hydrogen thyratrons to allow faster rise times, higher voltages, and higher energies. Rise times of about 10 ns are anticipated. The parameters to be studied include:

1. Gas species, purity, pressure, flow rate.
2. Electrode material, shape, surface condition.
3. Gap spacing.
4. Voltage pulse rise time, energy, peak voltage
5. Overvoltage conditions.
6. Statistical variations.